# This presentation premiered at WaterSmart Innovations

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# Generating Typical Hot Water Draw Patterns for Residential Building Energy Use

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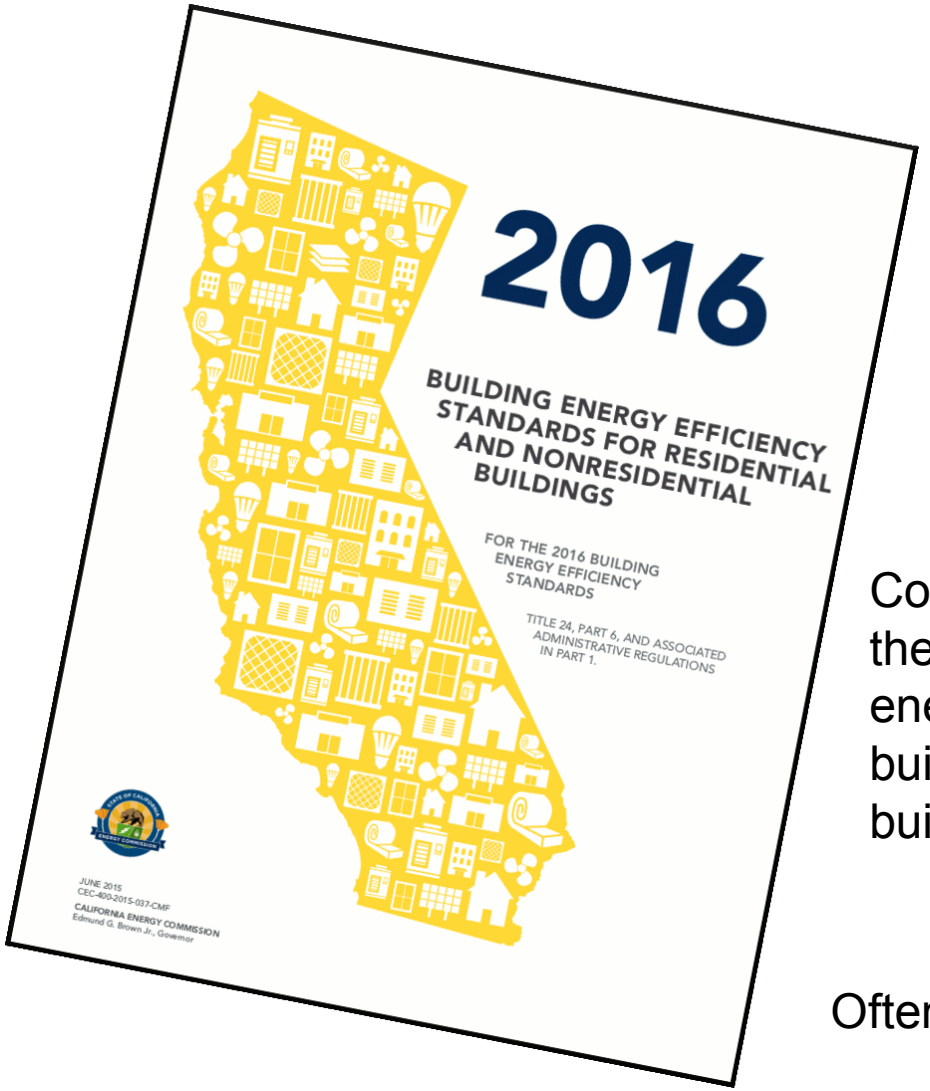
# California's Building Energy Efficiency Code




The Standards contain energy (and water) efficiency requirements for newly constructed buildings, additions to existing buildings, and alterations to existing buildings.

Compliance is demonstrated by comparing the energy use of a proposed building to the energy budget of an equivalent basecase building. The energy use is calculated with building simulation software.

Often referred to as "***Title 24***"

# What is Title 24

- Title 24 of  California Code of Regulations, Part 6 - California Energy Code
- Energy conservation standards for all residential and non-residential buildings throughout California
- Since 1978, updated every three years by the California Energy Commission
- Requires building permit applicants submit energy efficiency compliance documentation with permit

# Performance Compliance

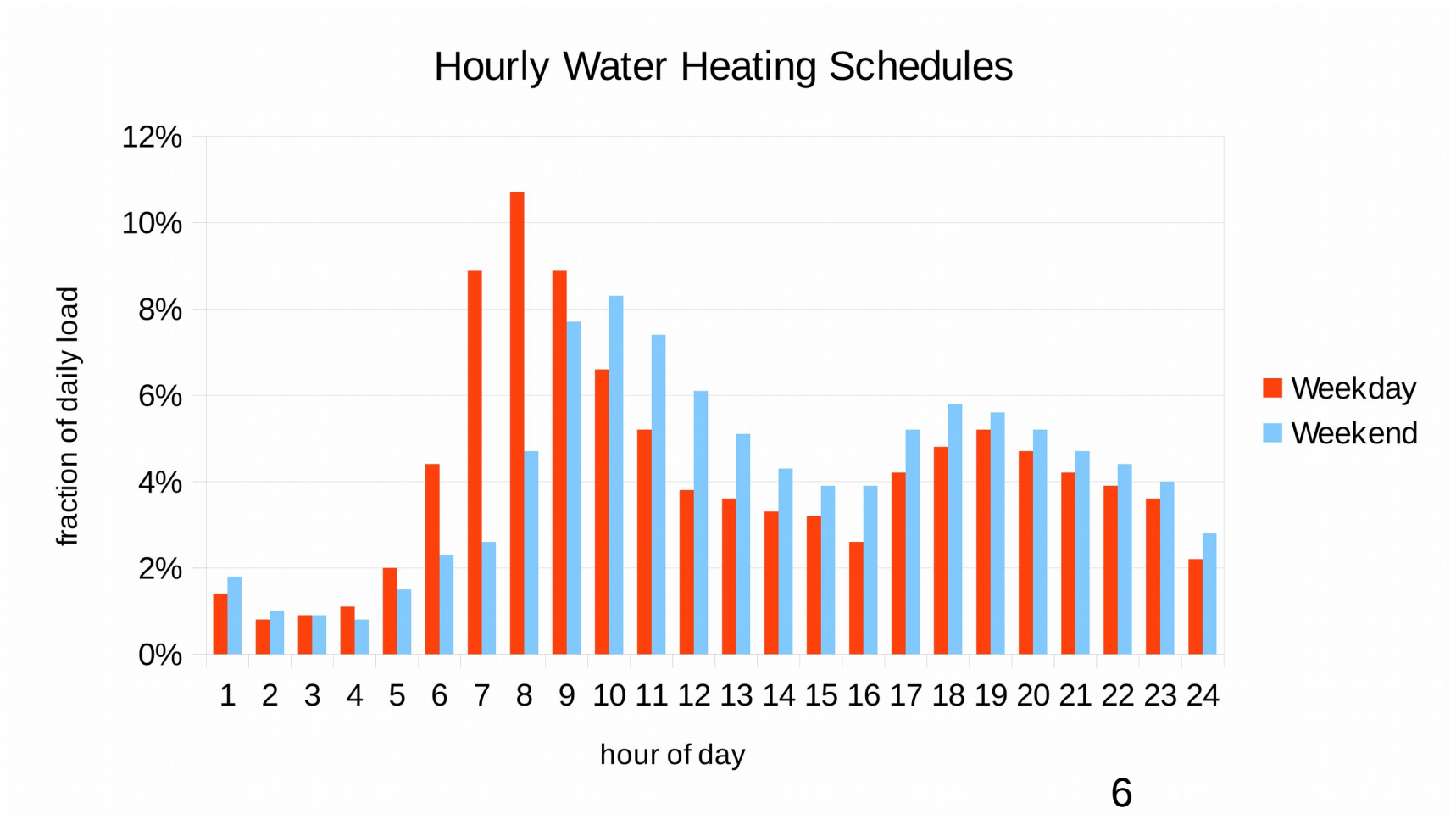
- Calculations to show proposed design uses less energy than it would if it met the Prescriptive requirements.
- Uses state-certified, free, open source energy modeling software:  CBECC-Res
  - Simulation as a rating tool, not a forecasting tool
  - Time Dependent Valuation (TDV) – different "price" of electricity every hour of year based on PUC cost model
  - Typical Meterological Year (TMY) –  16 weather files for state

# Revision Goals

- Improve efficiency calculations particularly for Heat Pump Water Heaters (HPWH)
  - High efficiency electric water heating is of interest for meeting the State Zero Net Energy goal for the 2019 Standards.
  - Current Energy Factor (EF) based model is inadequate for TDV
  - Model the interaction of the HPWH and the building
- Update the DHW loads model
  - Improve time of DHW electricity use for TDV
  - Diverse rather than average loads,
  - Include peaks that cause HPWH backup

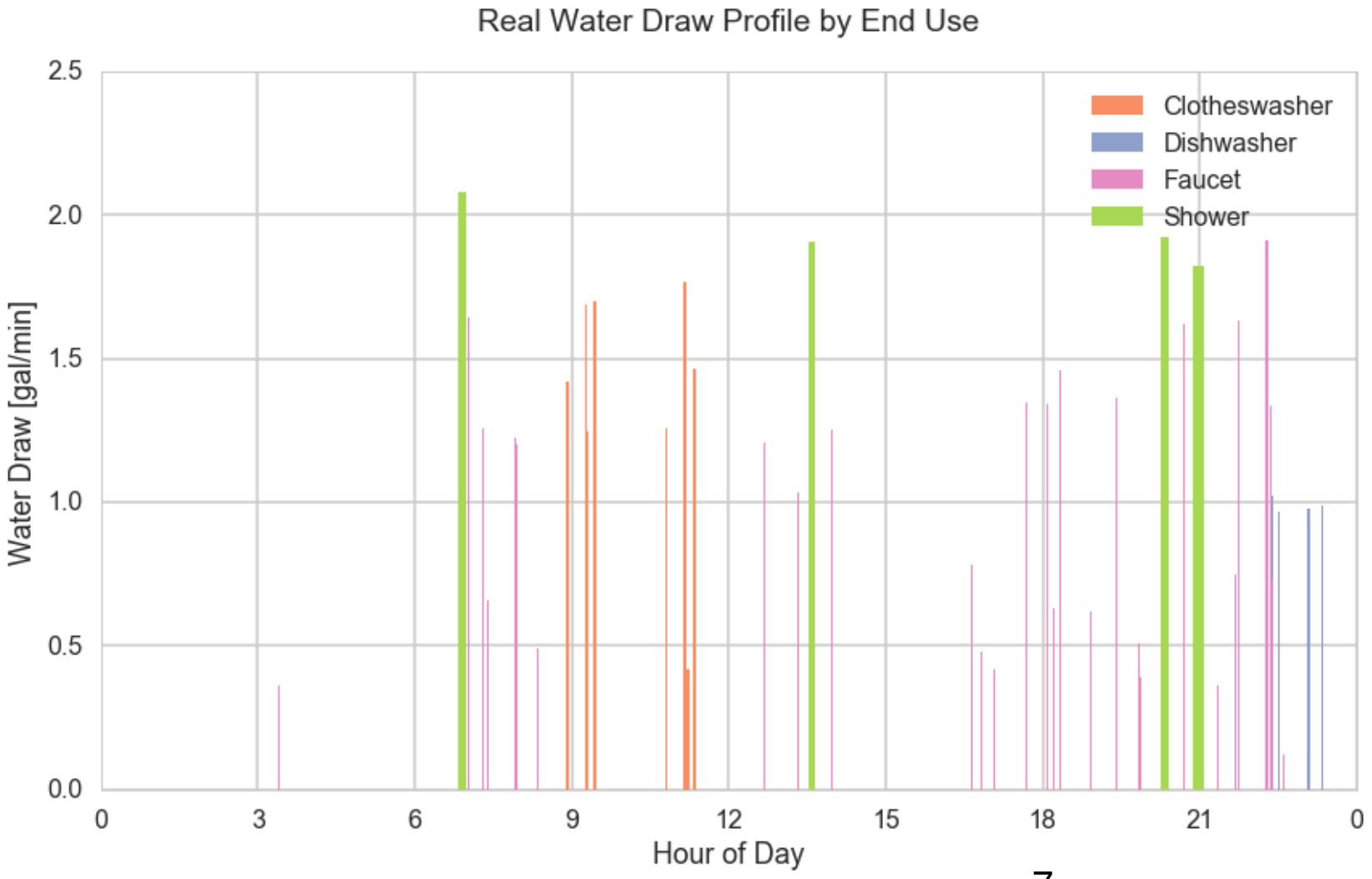
# Daily Hot Water Use

- Table RE-1 Hourly Water Heating Schedules
- (from 2013 Residential ACM Reference Manual)



# Hot Water Consumption

- actual data from field (California Single Family Water Use Efficiency Study, Aquacraft, Inc.  June 1, 2011)



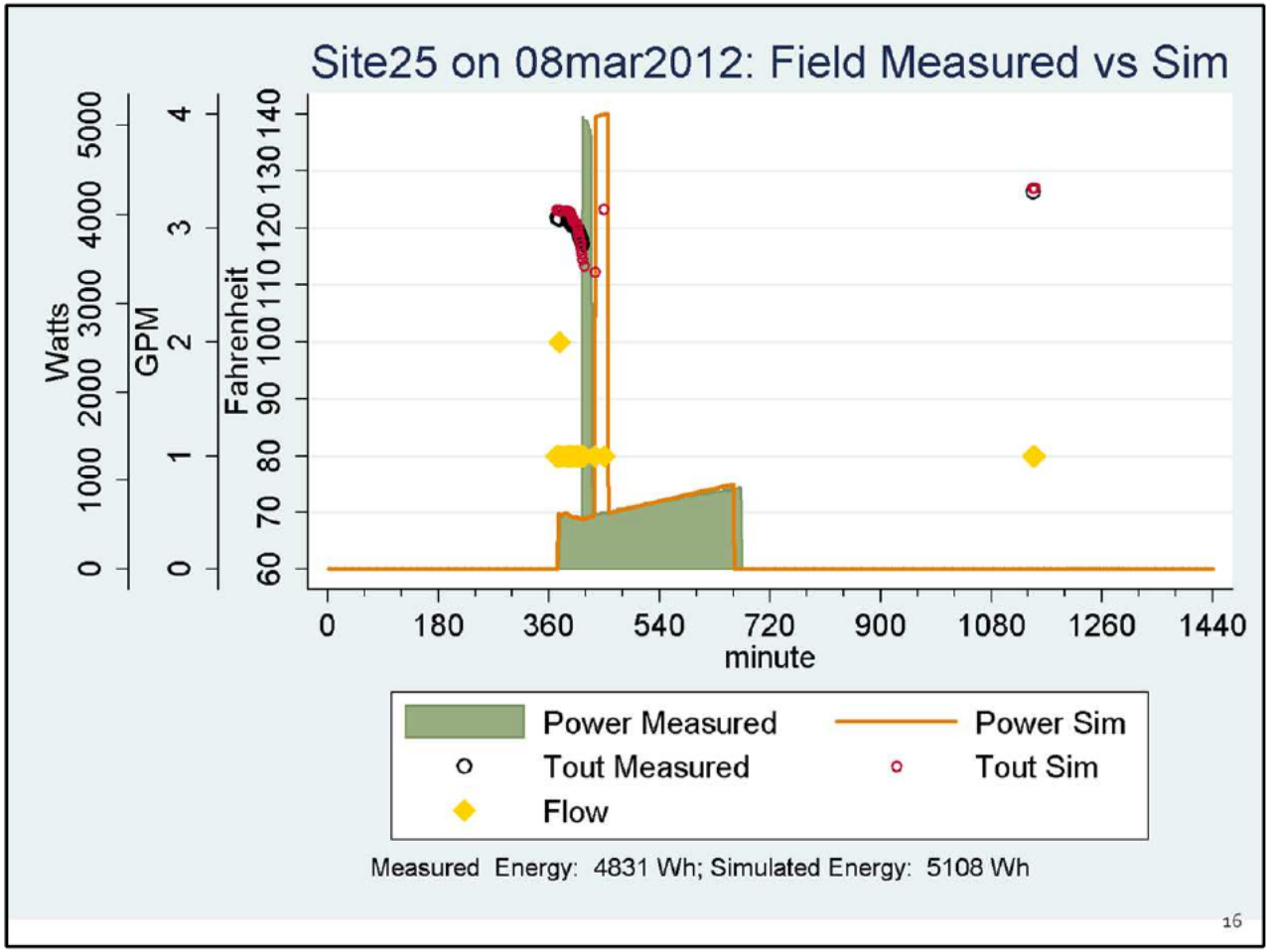
# Heat Pump Water Heaters



# Heat Pump Water Heaters

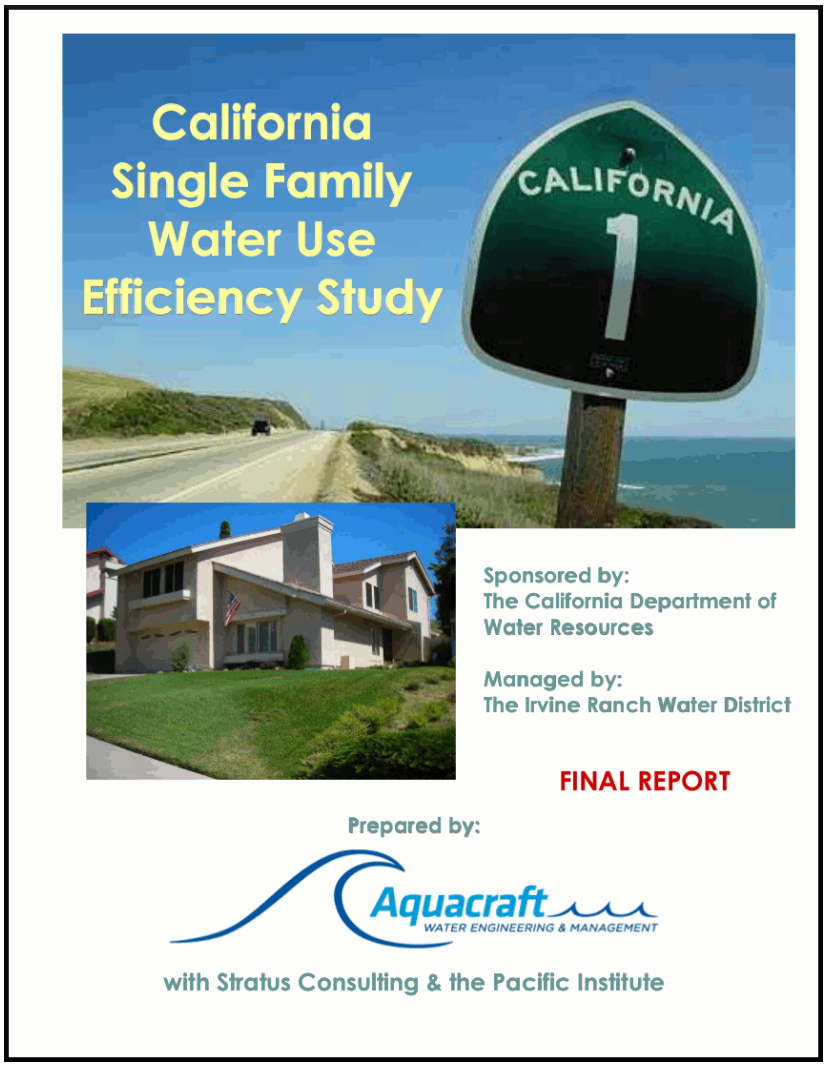
- very (energy) efficient
- heat water using air as the main heat source
- important for reducing carbon emissions
- compressor vs backup resistance

# Water Heater Simulation Models




source: Larson, Ben and Michael Logsdon, Heat Pump Water Heater - Quick Simulation Approach, ACEEE Hot Water Forum 2013, November 4 2013.

# Data on Hot Water Use

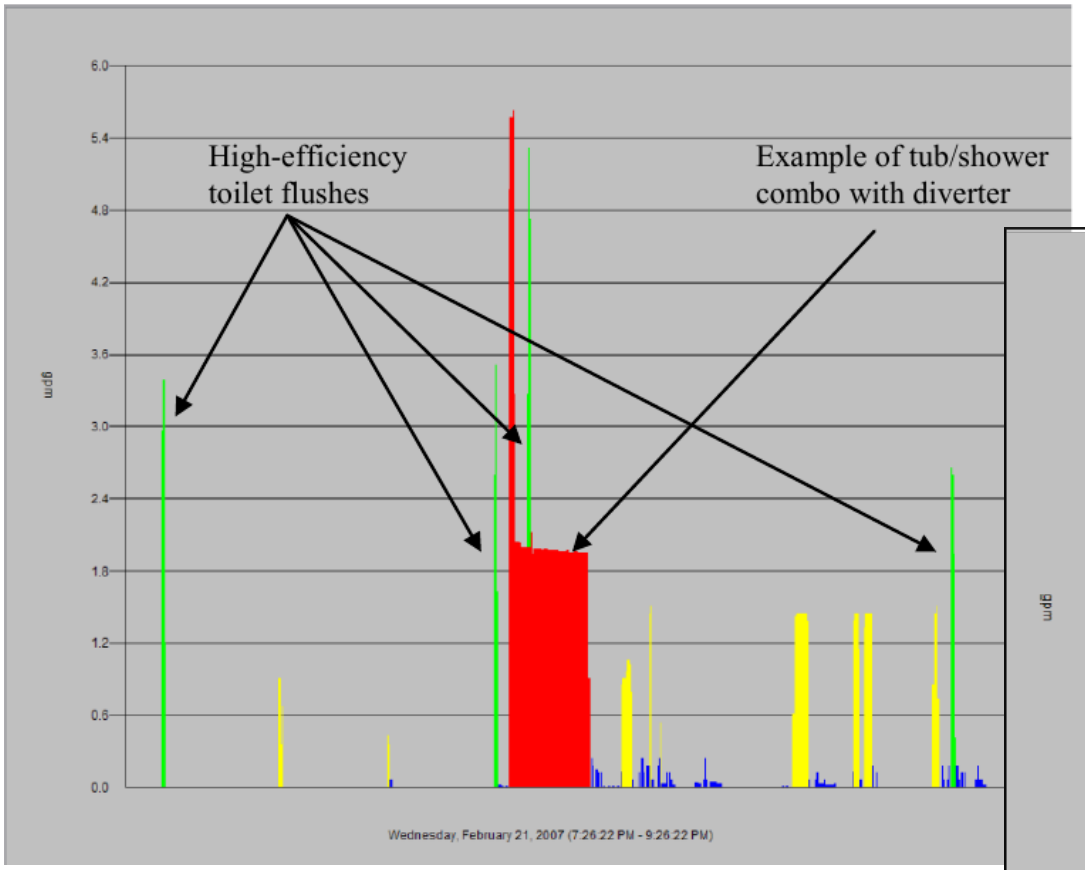


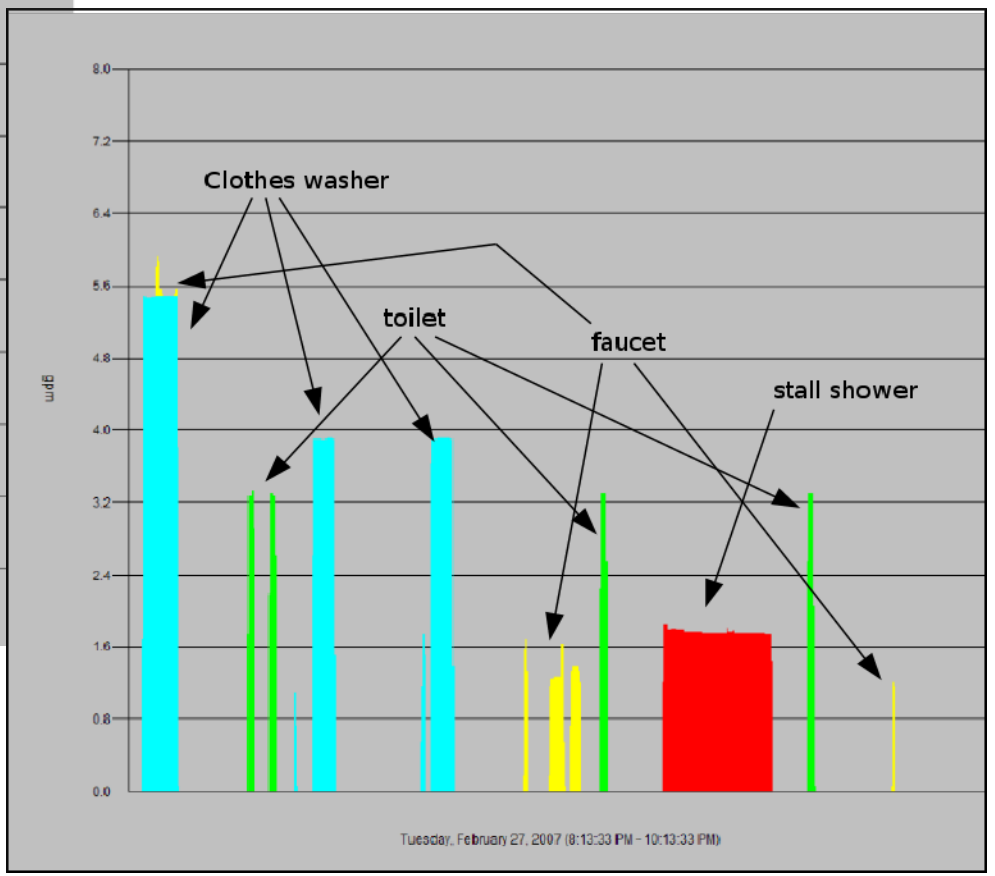
# California Single Family Water Use Efficiency Study

- flow trace data from water meters of each home
- flow readings at ten second intervals
- identify individual water use events and to categorize by end use.
- 735 single-family homes across ten water agencies throughout California

DeOreo, William B., Peter W. Mayer, Leslie Martien, Matthew Hayden, Andrew Funk, Michael Kramer-Duffield, Renee Davis, et al. *California Single Family Water Use Efficiency Study.* Aquacraft, Inc. for California Department of Water Resources, June 1, 2011.

# Flow Trace Analysis



# Standard Water Use Adjustments

- Aquacraft data total (hot and cold) water.
- Standardized hot water draws adjusted for:
  - Fixture efficiency
  - Hot Water Fractions
  - Structural Distribution Losses

# Standard Water Use Adjustments

| Type of Draw | Fixture Efficiency | Hot Water Fraction |
|---|---|---|
| Shower | ≤ 2.0 GPM | 66% [a] |
| Faucet | total reduced 4% | 50% [b] |
| Clothes Washers | total load volume = 12.65 gallons | 22% [b] |
| Dishwashers | total load volume = 5.0 gallons | 100% [c] |
| Baths | N.A. | 66% [a] |

notes:
a) assumes a 105 °F shower temperature, a 125 °F hot water setpoint, and 65 °F mains temperature
b) based on the REUWS2 study (Aquacraft, Inc. 2016) which used separate mains and water heater flow meters
c) assumed to be plumbed exclusively with hot water

# Structural Distribution Losses

- losses from long pipes that need to be cleared of cooled off hot water
- shower, faucet, and bathtub draws only
- based on the number of bedrooms in the house
- multipliers pre-adjust volumes so when applied by simulation tool will be same as originally

$$V_{adj} = \frac{V}{SDLM}$$

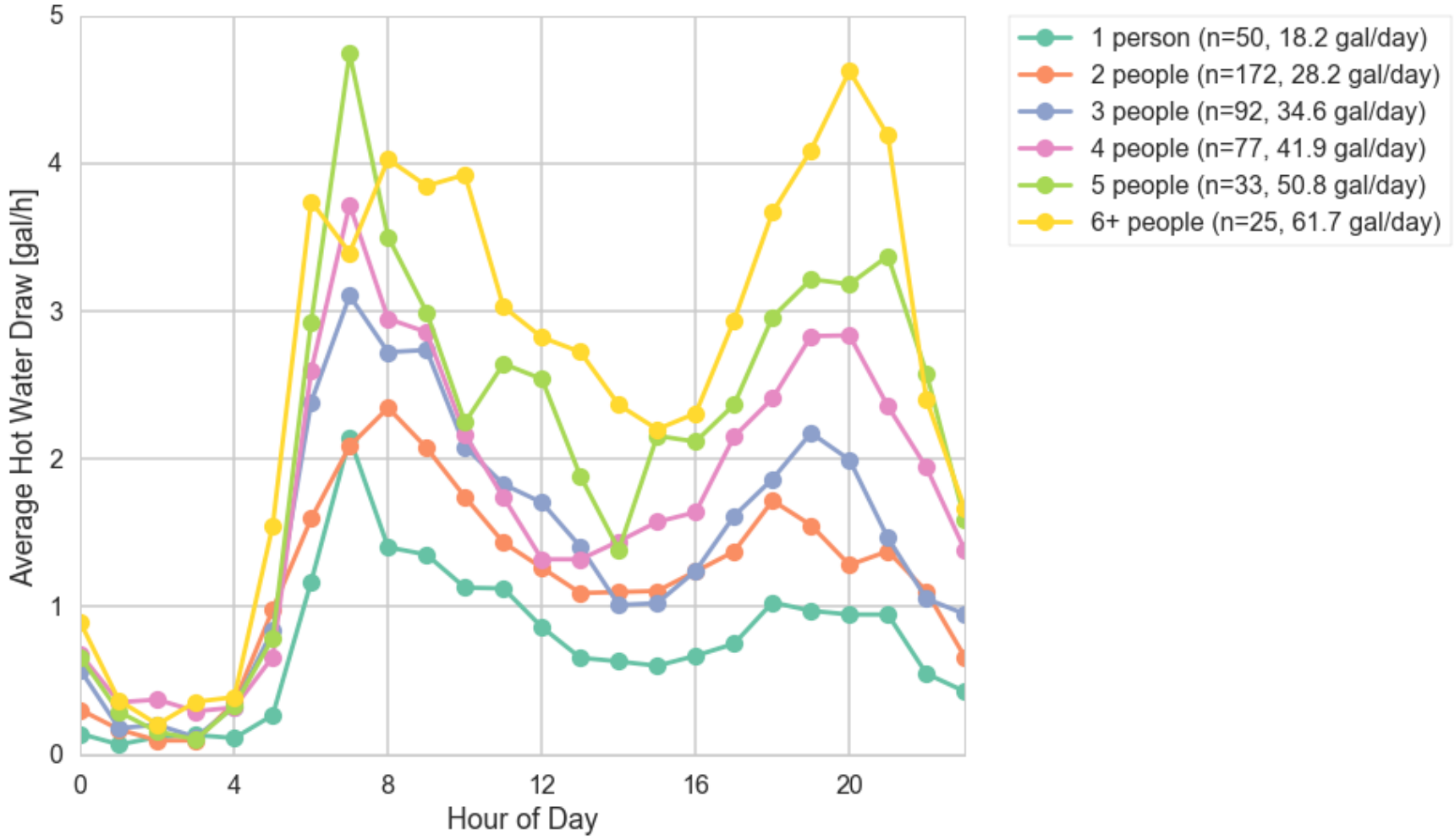
# Structural Distribution Multipliers

| Number of Bedrooms | SDLM |
|---|---|
| 0 | 1.076 |
| 1 | 1.109 |
| 2 | 1.171 |
| 3 | 1.272 |
| 4 | 1.341 |
| 5+ | 1.365 |

# Finding Typical Days

- actual days from dataset that closely match:
  - average daily end use subtotals, and
  - average hourly profile of the total water draw
- eight representative days
  - Monday through Sunday, plus a Holiday
  - for each occupancy level
- keep diversity of draw patterns observed in the field

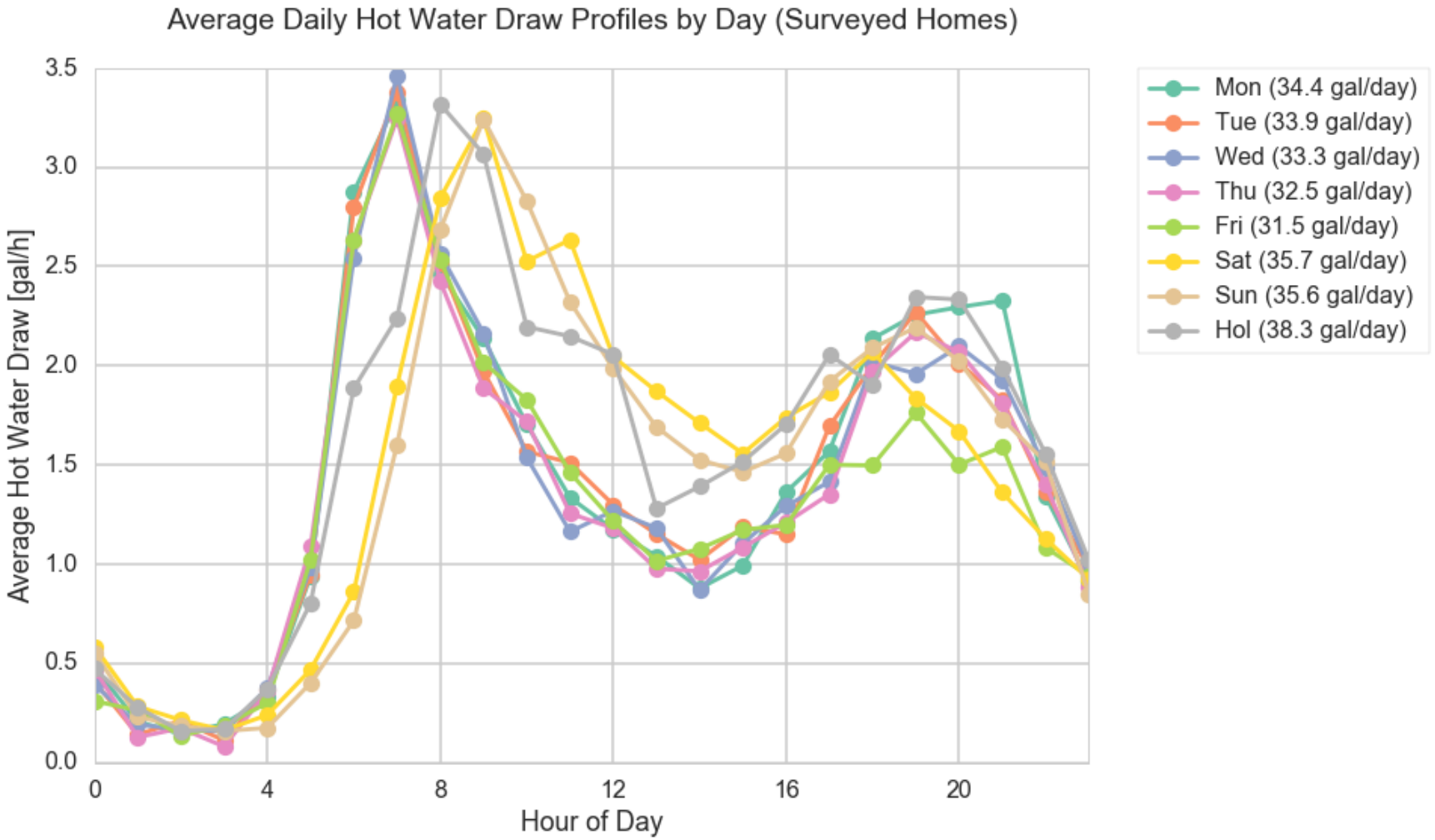
# Hourly Daily Hot Water Profiles by Number of Occupants



# Sample of Days

| Occupants | Homes | Weekdays | Weekends | Holidays | Total Days |
|---|---|---|---|---|---|
| 1 | 21 | 167 | 79 | 11 | 257 |
| 2 | 103 | 831 | 392 | 63 | 1286 |
| 3 | 59 | 489 | 218 | 30 | 737 |
| 4 | 48 | 394 | 182 | 28 | 604 |
| 5 | 17 | 139 | 63 | 9 | 211 |
| 6+ | 17 | 133 | 65 | 5 | 203 |
| All | 265 | 2153 | 999 | 146 | 3298 |

# Hourly Daily Hot Water Profiles by Day Type



# Grading Combinations of Days

- choose set of days that minimize the deviation

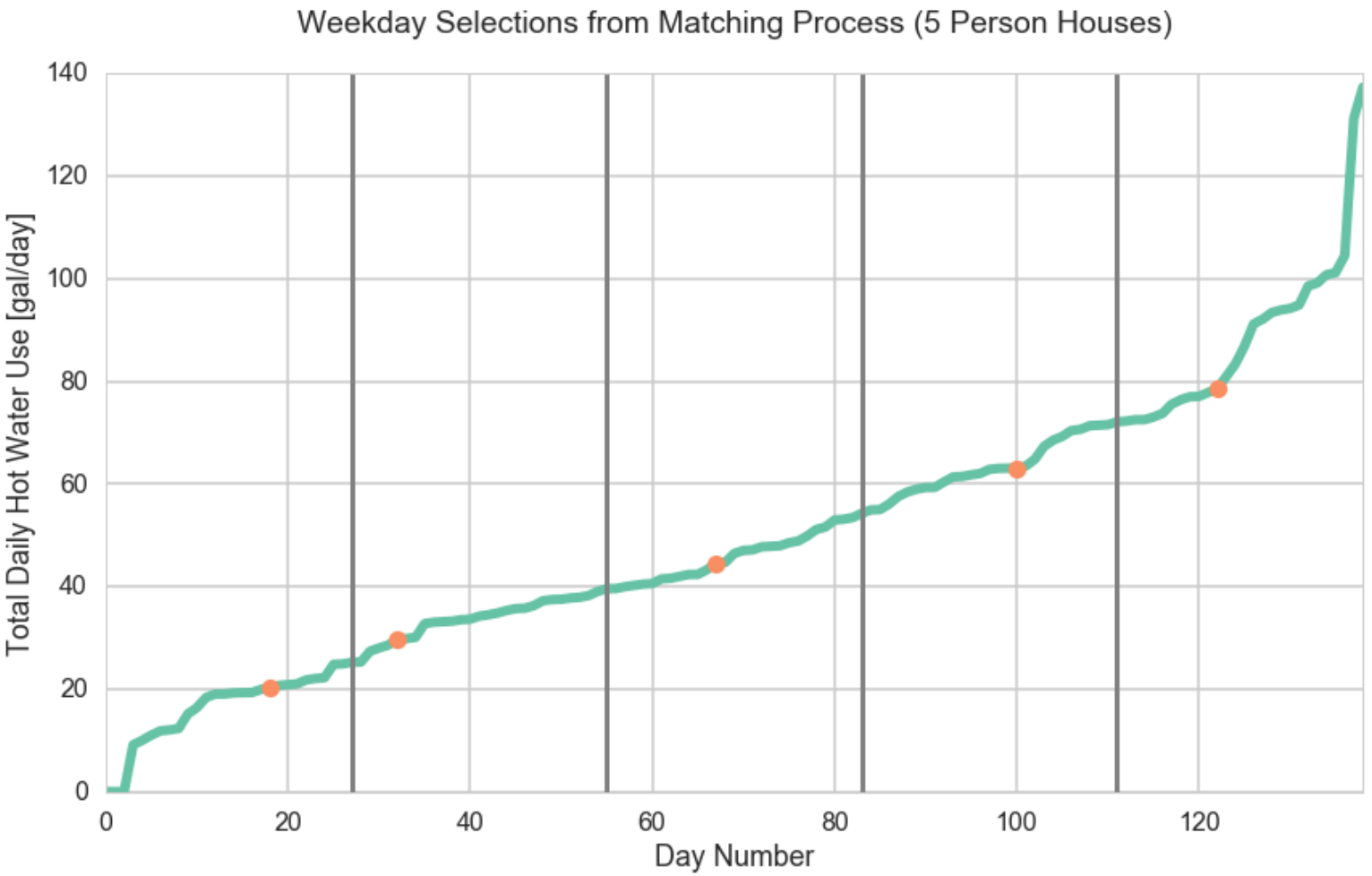
$$D = \sqrt{\left\{ \sum_{EndUses} \left( \frac{V_{EU}}{\overline{V_{EU}}} \right) \right\}^2 + \left\{ \sum_{h=1}^{h=24} \left( \frac{smooth(V_H)}{\overline{V_H}} \right) \right\}^2}$$

# Exhaustive Search? NO!

- exhaustive search of all possible combinations would be computationally prohibitive

$$\left[ \begin{array}{l} \binom{167}{5} \times \binom{79}{2} \times 11 + \binom{831}{5} \times \binom{392}{2} \times 63 + \\ \binom{489}{5} \times \binom{218}{2} \times 30 + \binom{394}{5} \times \binom{182}{2} \times 28 + \\ \binom{139}{5} \times \binom{63}{2} \times 9 + \binom{133}{5} \times \binom{65}{2} \times 5 \end{array} \right] = 15{,}950{,}537{,}741{,}321{,}187{,}189$$

# Search Process



# Search Algorithm

Evaluate all combinations of days from first and last bins.

Keep best N combinations

Evaluate all combinations of days from bins 2 and 4

Keep best N combinations

Evaluate all of the combinations of days from those two sets

Keep best N combinations

Evaluate all of the combinations of that set with days in bin 3

Select best combination

# Day Sets

- 6 occupancy levels
- 8 day types
- 48 day sets

# Sample Day
## (3 Person, Day 2, partial)

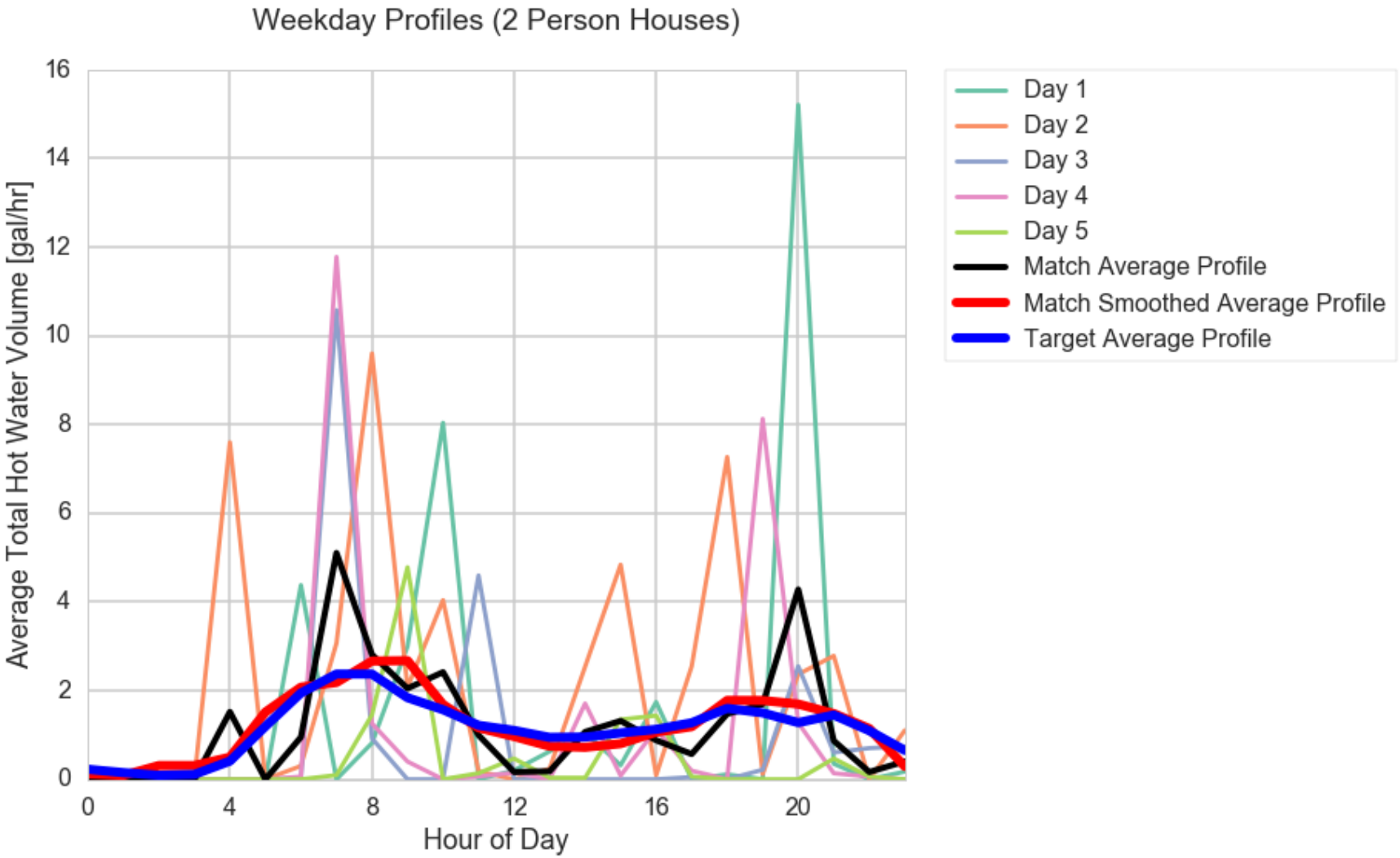
| draw type | start (hr) | duration (min) | mix flow (GPM) |
|---|---|---|---|
| FAUC | 0.15 | 0.333 | 1.336 |
| FAUC | 5.92 | 0.167 | 0.317 |
| FAUC | 7.91 | 0.167 | 0.317 |
| FAUC | 8.44 | 0.667 | 0.962 |
| SHWR | 8.53 | 7.500 | 1.572 |
| FAUC | 8.76 | 0.167 | 0.543 |
| FAUC | 8.81 | 0.333 | 0.362 |
| FAUC | 8.92 | 1.167 | 0.815 |
| FAUC | 8.93 | 0.167 | 0.860 |
| SHWR | 8.96 | 5.167 | 1.572 |
| FAUC | 8.98 | 0.167 | 1.947 |
| FAUC | 9.08 | 0.167 | 1.268 |
| … | … | … | … |

# Representative Draw Profile
## 2 person weekdays

| End Use | Target Average [gal/day] | Match Average [gal/day] |
|---|---|---|
| Shower | 12.71 | 12.68 |
| Faucet | 10.80 | 10.85 |
| Bathtub | 1.41 | 1.18 |
| Clotheswasher | 2.41 | 2.23 |
| Dishwasher | 1.76 | 2.00 |
| Total | 29.09 | 28.94 |

# Representative Draw Profile

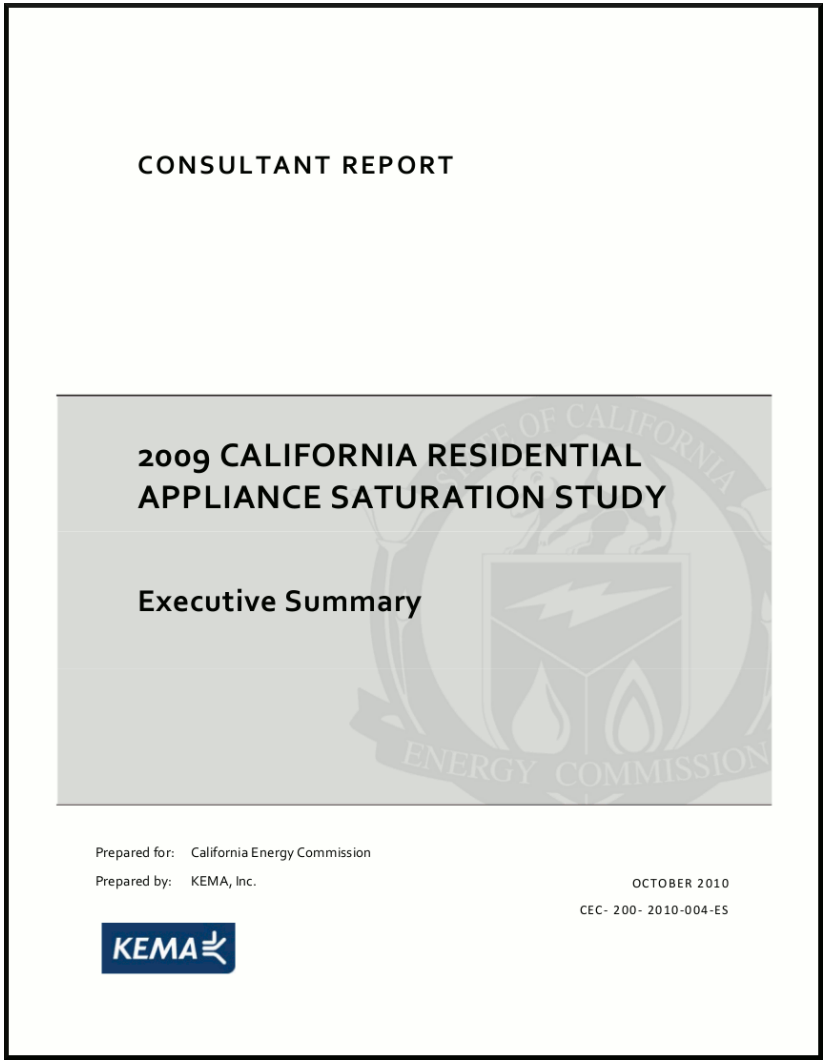
## 2 person weekdays



# Number of People per House

- houses expected to remain it use ~50+ years
- different people move into and out of house over that time
- hot water use depends on number of people in house
- Title 24 energy use modeled for only one year

# Data on People and Houses



CONSULTANT REPORT

2009 CALIFORNIA RESIDENTIAL APPLIANCE SATURATION STUDY

Executive Summary

Prepared for: California Energy Commission

Prepared by: KEMA, Inc.

OCTOBER 2010

CEC- 200- 2010-004-ES

KEMA

# *RASS occupancy data for Single Family Homes*

| Number of People | Number of Bedrooms | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5+ |
| 1 | 42.3% | 26.4% | 14.0% | 7.4% | 6.0% |
| 2 | 32.7% | 39.3% | 37.4% | 27.5% | 16.9% |
| 3 | 9.5% | 14.3% | 18.3% | 17.3% | 14.4% |
| 4 | 12.3% | 8.5% | 16.1% | 26.6% | 23.4% |
| 5 | 2.0% | 6.6% | 8.1% | 13.0% | 17.2% |
| 6+ | 1.1% | 5.0% | 6.2% | 8.3% | 22.2% |

# Sample Draw Profile

Single family, three bedroom schedule for January

| Day | Day of Week | Occupancy Level | Day Type & Match Number |
|---|---|---|---|
| Jan. 1 | Thu | 3 | Holiday 1 |
| Jan. 2 | Fri | 1 | Weekday 3 |
| Jan. 3 | Sat | 2 | Weekend 2 |
| Jan. 4 | Sun | 4 | Weekend 1 |
| Jan. 5 | Mon | 2 | Weekday 5 |
| Jan. 6 | Tue | 5 | Weekday 2 |
| Jan. 7 | Wed | 2 | Weekday 4 |
| Jan. 8 | Thu | 2 | Weekday 1 |
| Jan. 9 | Fri | 2 | Weekday 5 |
| Jan. 10 | Sat | 1 | Weekend 2 |
| Jan. 11 | Sun | 2 | Weekend 1 |
| Jan. 12 | Mon | 2 | Weekday 2 |
| Jan. 13 | Tue | 2 | Weekday 1 |
| Jan. 14 | Wed | 1 | Weekday 3 |
| Jan. 15 | Thu | 4 | Weekday 4 |

# Typical Hot Water Draw Patterns

- generated as used from
- days by number of people
  - 5 weekdays
  - 2 weekend days
  - 1 holiday
- list of 365 people days for number of bedrooms
- events are total mixed water flow rate and duration
- flow rates depend on efficiency standards and cold water temperatures

# for more information

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